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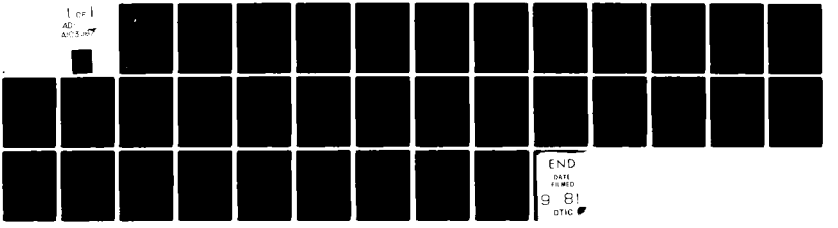

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Technical Report

RESEARCH IN FUNCTIONALLY DISTRIBUTED COMPUTER SYSTEMS DEVELOPMENT

Kansas State University

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Principal Investigator

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VOLUME VIII

A DEADLOCK PREVENTION ALGORITHM FOR DISTRIBUTED DATA BASE MANAGEMENT SYSTEM

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-ABSTRACT-

The problem of deadlock in distributed data base management is analyzed in terms of performance effects of potential deadlock handling schemes. The performance tradeoffs of deadlock detection and deadlock prevention for distributed data base management systems are compared. Since the run-time overhead in deadlock prevention is projected to be less than for deadlock detection, an algorithm for preventing deadlocks in distributed data base systems is developed. The critical information for the deadlock prevention algorithm is maintained in a shared record list. The shared record list contains all shared access records for a set of tasks. Shared records lists are maintained dynamically by the run-time system. A proof that the algorithm prevents deadlocks in a distributed data base management system is provided along with a comprehensive example.

A Deadlock Prevention Algorithm for Distributed Data Base Management Systems[1]

Technical Report CS77-02

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Abstract

The problem of deadlock in distributed data base management is analyzed in terms of performance effects of potential deadlock handling schemes. The performance tradeoffs of deadlock detection and deadlock prevention for distributed data base management systems are compared. Since the run-time overhead in deadlock prevention is projected to be less than for deadlock detection, an algorithm for preventing deadlocks in distributed data base systems is developed. The critical information for the deadlock prevention algorithm is maintained in a shared record list. The shared record list contains all shared access records for a set of tasks. Shared records lists are maintained dynamically by the run-time system. A proof that the algorithm prevents deadlocks in a distributed data base managment system is provided along with a comprehensive example. A discussion of the efficiency of the deadlock prevention algorithm indicates that partitioning the data base into sub-schemas reduces the overhead.

Key Words and Phrases:

Distributed data base management systems, deadlock prevention, system deadlocks.

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1 Introduction

One of the major trends in computer systems is toward the decentralization of resources and facilities. This phenomenum has lead to a requirement for distributed data base management systems. A distributed DBMS permits an application program executing on a processor in a computer network to access data on any other node in the network. In an optimal situation the only limits on data access are communication linkages and security. A distributed DBMS relies upon its underlying network for communication facilities. The basic data base software in a distributed system is functionally identical to a centralized (one machine) system.

From the preceding statements it appears that a distributed DBMS can be realized by interfacing a centralized data base system with a network communicati facility. However, as indicated by Fry and Sibley [10], when a data base system is extended to operate over several machines a whole new class of problems arises while many existing problems become more complex. Among those problems that are complicated by the distribution of the data base is that of deadlock. This paper proposes a method for preventing deadlock in a distributed data base system. The algorithm stated here is intended to avoid deadlock in a manner that is transparent to the application program and with minimal effect on processes that would not be involved in a deadlock situation.

2. Distributed Data Bases Systems

Before the presentation of the deadlock prevention algorithm can occur, terminology concerning data base management systems in general and distributed data base systems in particular must be established. A schema is a logical description of a data base. The portion of a schema that may be accessed by a particular application program is specified by the sub-schema associated

with that program. The sub-schema defines the data records that the program may operate upon and indicates the logical relationships among the records in the data base.

In a centralized data base system, the application program, sub-schema and data base software all reside on one processor which is physically connected to the secondary storage containing the data base. A distributed data base management system has resources and their control spread among the processors of a computer network. In a distributed DBMS, an application program executing on one network node may access data that reside at several distinct nodes. A computer that executes data base application programs is a host machine. A back-end machine is one which controls access to data. A machine with both capabilities is termed a bi-functional machine. Figure 1 protrays a distributed DBMS with host, back-end, and bi-functional nodes. A discussion of the general organization of distributed data bases can be found in Reference [18].

In order to implement a distributed DBMS, the software required for a centralized DBMS is necessary plus some communication and control software. As indicated in Reference[18], communication between application programs and data base tasks can best be accomplished by means of a generalized message system which is capable of handling communication among heterogeneous machines. The message system must also allow for transmission over a wide range of inter-machine connections, from conventional phone lines (typically 1200 baud) to shared memory (approximately 10M baud).

A group of machines tied together via memory-to-memory linkages is known as a cluster. A network can be formed from a collection of clusters joined by lower speed connections. In a distributed DBMS communication between machines in the same cluster can occur with little overhead. However, intercluster communication may result in noticeable performance degradation.

The impact of intermachine communication upon system performance is an important consideration in the treatment of deadlock in a distributed DBMS.

3. Deadlock in a distributed DBMS

In general, deadlock occurs when two or more processes request a set of shared resources in a sequence that results in the activation of each process being dependent upon the acquisition of a resource held by another process whose activation is also blocked. A considerable amount of study has been done on the deadlock problem of operating systems [5,6,9,12-14,19-20]. The particular form of deadlock under consideration in this report involves processes that are data base application tasks residing on (potentially) different machines in a data base network. The shared resource is a collection of records dispersed among the data bases of the system that may be updated by more than one application program. It is assumed that no user imposed restrictions concerning accessibility have been placed upon the data records. This form of deadlock is a DBMS problem, not a user problem. The means of treating deadlock must be totally transparent to the application program.

The special difficulty of deadlock in a distributed data base is that since there is no central control point in the network, the responsibility for noting the actual or potential occurrence of a deadlock situation can not easily be assigned. The task requesting the resource can be informed that the request was unable to be fulfilled. However, if that resource is controlled by one (or more) different processors, considerable manipulation and intermachine communication would be required to determine if a deadlock situation exists.

4. Deadlock Detection and Prevention

There are two basic mechanisms for treating the deadlock problem [4]. One approach is to prevent deadlock before it can occur. Deadlock prevention requires a prior knowledge of the shared records to be operated upon by all active application tasks in the system. The alternative to deadlock prevention is deadlock detection which involves noting the existence of a deadlock situation, and then resolving the dilemma. Generally, a deadlock situation can be resolved by halting one of the competing processes and freeing its resources for access by other processes. However, task "rollback" is detrimental to system performance and in some cases infeasible.

In a distributed DBMS, both deadlock prevention and detection produce considerable overhead; particularly if intercluster communication results. Deadlock prevention in a distributed data base requires that records that may be shared among several tasks (and updated by at least one) be identified. For this information to be meaningful, only the records shared with currently active tasks should be included. This implies that whenever a task that updates shared records enters the system the list of shared records must be revised. When this has taken place, the new task can proceed. Whenever a need to access a shared record arises, a prevention algorithm can be invoked to determine if the access may proceed. If not, the task is blocked until the resources are available.

The main cause of overhead in deadlock prevention in a distributed DBMS is the computation and communication of the list of shared records for active tasks. This is a continual operation which must occur whenever tasks are created and destroyed. As in all prevention schemes, some time is devoted to avoiding deadlocks which would not have occurred during a particular execution since a task may have access rights to many more records than it actually uses.

Deadlock detection schemes represent an a posteriori approach to the problem of avoiding deadlocks. In a distributed data base system, deadlock detection involves first identifying a set of two or more tasks blocking each other from a collection of shared records. Generally a "timeout" mechanism which involves noting that the effected tasks have been waiting for longer than some fixed time is used in deadlock detection. Once the set of deadlocked tasks and the conflicting resources are identified, one of the tasks must be rolled back to some point that will free the resources necessary to break the deadlock. Rollback involves restoring all data to the values held before the operations being retracted were performed. In a distributed environment, the data base operations may be initiated on one host processor and carried out by several different back-end processors. Rollback action would have to be initiated by the host processor and then carried out by the back-end processor in a manner analagous to the execution of a standard data base access. This will necessitate considerable message transmission activity to start and synchronize the rollback operation.

An additional negative performance factor in the deadlock detection approach is that tasks not involved in the deadlock situation can be effected if they have accessed data written by the sequence of commands being rolled back. In this case, the task accessing the data would also have to be rolled back. It is possible for the rollback to cascade throughout the system in the worst case.

The deadlock detection algorithms described in references [2,3,7,15] all require a dynamic list of processes and the records that they access. This information is similar to that required in a deadlock prevention scheme. Acquiring and maintaining an accessibility list for deadlock detection could require a heavy communication load in a distributed system as in the case of deadlock prevention.

A comparison of the two alternatives for avoiding deadlock indicates that both types of algorithms would require some form of a record accessibility list. Since deadlock prevention requires continual computational and communication activity to avoid deadlock whereas deadlock detection measures are most likely to be invoked infrequently, there is potentionally more overhead in deadlock prevention. However, the overhead is fixed and the prevention algorithm has no effect upon processes that may not be involved in any deadlock situations. In a distributed data base system, the rollback and timeout mechanisms of deadlock detection could result in substantial computation and communication overhead and also the rolling back or blocking of tasks not involved in the deadlock situation.

Because of the uncertain and potentially serious performance degradation that may result from rollback in a distributed DBMS deadlock prevention is a safer strategy for handling deadlocks in a distributed data base environment. Thus, this paper concentrates upon deadlock prevention.

5. Information Required to Prevent Deadlock

In a distributed DBMS utilizing the proposed prevention algorithm, each back-end processor will be responsible for preventing deadlock situations involving the portion of the data base under its control. Since the back-end processor performs the function of manipulating the data, it is best suited to assume the responsibility for deadlock prevention. In this way, the prevention of deadlock is removed from the application task.

For each active task that it is serving, the back-end processor maintains a list of records that may be accessed by several tasks and updated by at least one task.

The shared record list is derived from the sub-schema of task. When a task is initiated its shared record list is circulated among the back-end

processors to determine if any interaction with other task exists. A list of interacting tasks is maintained by the back-end processors. In order to minimize the communications overhead upon task initiation, each back-end processor can maintain a list which indicates those back-end processors which may control records shared with any given sub-schema. Only these back-ends with potential interaction need be contacted. Upon task termination similar action must be taken to withdraw the task and its records from the task interaction and shared record lists. The shared record list is conceptually similar to the process set of Chu and Ohlmacher [4].

6. Deadlock Prevention

An algorithm for the prevention of deadlock in a distributed DBMS is developed in this section. Initially some notational conventions must be established.

Definition 1 (Notation)

1. r_j - a record in the data base
2. T_K - an application task.
3. R_K - potential shared record list of T_K. A set of shared records is accessed by several tasks and updated by at least one.
4. X_T - a task interaction list. A set of tasks whose potential shared record lists have non-empty pairwise intersections.
5. S_T - the shared record list of X_T. All records appearing in more than one potential shared record list of the tasks in X_T.
6. B_k - the back-end processor executing a data base request for T_K.
7. $S_{T,K}$ - the shared record list of a set of tasks T on back-end processor K. A record in a shared record list is marked with a task identifier when it is requested or locked.
8. m ($S_{T,K}$) - the number of distinct tasks that have records marked in $S_{T,K}$.
9. L (S_T) - the number of distinct tasks that have records locked in S_T.

For a given task interaction list X_T, a copy of S_T, the shared record list, is maintained on each back-end processor executing data base operations for a task in X_T.

In order to properly prevent deadlock, the state of the system immediately prior to a deadlock state must be described and recognized. If an algorithm can develop which insures that the distributed DBMS will never enter a state that can immediately lead to deadlock, then the algorithm will prevent deadlock. First let us formally define deadlock.

Definition 2

A set of tasks $T = \{T_1, T_2, \ldots, T_m\}$, $m \geq 2$, is deadlocked if for $1 \leq i \leq m-1$, T_i is blocked by T_{i+1} and T_m is blocked by T_1.

Example 1

Assume there are five tasks T_1, T_2, T_3, T_4, T_5, active in the system. Let

$$R_1 = \{r_1, r_2, r_3\}$$
$$R_2 = \{r_1, r_4, r_7\}$$
$$R_3 = \{r_3, r_5, r_7\}$$
$$R_4 = \{r_6, r_9\}$$
$$R_5 = \{r_8, r_9\}$$

Then

$$X_1 = \{T_1, T_2\}$$
$$X_2 = \{T_1, T_2\}$$
$$X_3 = \{T_2, T_3\}$$
$$X_4 = \{T_1, T_2, T_3\}$$
$$X_5 = \{T_4, T_5\}$$

and

$$S_1 = \{r_1\} \qquad S_3 = \{r_7\} \qquad S_5 = \{r_9\}$$
$$S_2 = \{r_3\} \qquad S_4 = \{r_1, r_2, r_7\}$$

If T_1 is blocked by T_2, T_2 is blocked by T_3, and T_3 is blocked by T_1, then X_4 is deadlocked.

Definition 2

A set of tasks $T = \{T_1, T_2, \ldots T_m\}$, $m \geq 2$, is in a deadlock-prone state if there is a sequence of unfulfillable requests that can be issued by the tasks in T that will place T in a deadlocked state.

Lemma 1

A set of tasks cannot enter a deadlock state without first entering a deadlock-prone state.

This result follows immediately from Definitions 2 and 3.

Example 2

Consider the set of tasks in the previous example.

Assume that

T_1 has locked r_3;

T_2 has locked r_1;

and T_3 has locked r_7.

T is in a deadlock-prone state since the following sequence of commands results in a deadlock state:

T_1 requests r_1

T_2 requests r_7

T_3 requests r_3;

since T_1 will be blocked by T_2, T_2 will be blocked by T_3, and T_3 will be blocked by T_1.

Lemma 2 indicates a method for detecting the existence of a deadlock-prone state.

Lemma 2

A set of tasks T is in a deadlock-prone state if and only L $(S_T) = |T|$.

Proof

Let $T = \{T_1, T_2, \ldots T_k\}$ where the numbering of tasks is arbitrary, $k \geq 2$.

We will first show that if L $(S_T) = |T|$, then T is in a deadlock-prone state.

Let $\{r_1, r_2, \ldots, r_k\} \subseteq S_T$.

Let Q_0 be the state of the system when L $(S_T) = |T|$.

Since L $(S_T) = |T|$, each task in T must have at least one record locked. We can assume that for $1 \leq i \leq k$, r_i is locked by T_i.

Since each record in S_T is contained in the intersection of the record lists of at least two tasks, we can assume that for $1 \leq i \leq k-1$, $r_{i+1} \in R_i \cap R_{i+1}$ and $r_1 \in R_k \cap R_1$.

From system state Q_0, let task T_i request record r_{i+1}, $1 \leq i \leq k-1$, and let task T_k request record r_1.

The system will then enter state Q_1 in which the following condition holds:

T_1 is blocked by T_2;

T_2 is blocked by T_3;

$\vdots$

T_{k-1} is blocked by T_k;

T_k is blocked by T_1;

Thus state Q_1 is a deadlock state.

From Definition 3, it follows that Q_0 is a deadlock-prone state. Therefore L $(S_T) = |T|$ implies that T is in a deadlock-prone state.

It must now be demonstrated that the existence of a deadlock-prone state implies that L $(S_T) = |T|$.

Let Q_0 be a dealock-prone state such that there is a sequence of unsatisfiable requests which lead to deadlock state Q_1.

Assume that the tasks in T are blocked in state Q_1 as shown;

T_1 is blocked by T_2;

T_2 is blocked by T_3;

$\vdots$

T_{k-1} is blocked by T_k;

T_k is blocked by T_1;

If a task is blocking another task, the intersection of their record lists must be non-empty. Therefore, there is a set of records $\{r_1, r_2, \ldots r_k\} \subseteq S_T$ such that

for $1 \leq i \leq k-1$, $r_{i+1} \in R_i \cap R_{i+1}$

and $r_1 \in R_k \cap R_1$.

Since each task in T is blocking another task, each task in T must have at least one record locked in state Q_1. Therefore in state Q_1, $L(S_T) = |T|$.

Since Q_1 was reached from Q_0 by a sequence of unsatisfiable requests, the set of records locked in Q_1 is identical to the set of records locked in Q_0. Therefore in state Q_0, $L(S_T) = |T|$ where Q_0 is a deadlock-prone state.

Example 4

In the deadlocked and deadlock-prone states of preceeding examples,

$S_4 = \left\{ \begin{matrix} r_1, & r_3, & r_2 \\ 1 & 3 & 2 \end{matrix} \right\}$ where the integers beneath the records indicate the task locking the record.

Thus, $L(S_4) = 3$.

6. An Algorithm for the Prevention of Deadlock

From Lemma 2, we can see that if $L(S_T) < |T| - 1$ for all sets of shared records, then the system will be free of deadlock. This relationship between the number of tasks potentially and actively sharing data and the occurrence of deadlock forms the basis for a deadlock prevention algorithm.

Three commands and a response are necessary for operation in a deadlock-free environment. All commands and responses are transmitted among back-end processors. The commands are LOCK, UNLOCK and REQUEST. When a task desires to update a shared record, the back-end processor controlling that record issues either a LOCK or REQUEST command to the other back-end processors controlling records of tasks in any of the task interaction lists of the requesting task. The decision as to whether LOCK or REQUEST is sent is based upon relative task priorities. LOCK commands are sent to the back-end processors of lower priority tasks, while back-end processors serving tasks of higher priority receive REQUEST commands. If a back-end processor that has received a REQUEST command determines that the record is available, it issues a POSITIVE response. It is important to note that under the deadlock prevention algorithm a negative response is not necessary since a back-end processor issuing a REQUEST for an unavailable record or a REQUEST that would lead to deadlock will receive a LOCK command which invalidates the REQUEST. The UNLOCK command relinquishes control of a record. The detailed effect of each function is explained in the following definitions. A command or request is not necessary for the query of a shared record. A check of the shared record list will indicate if the record is available. In this discussion the term "update" will indicate both a read and write, while "query" implies a read only.

Definition 4

The REQUEST r_j, T_k command issued by B_k to B_i results in the following operations:

If for all $S_{T,i}$ containing r_j,

a. r_j is unmarked in $S_{T,i}$ and

b. either T_k has a record marked in $S_{T,i}$ or $m(S_{T,i}) \leq |M_T|-1$ for $|M_T| \leq 2$.

then B_i marks r_j in all $S_{T,i}$ with the identifier of T_k and transmits a POSITIVE r_j, T_k response to B_k.

Otherwise B_i does not respond to B_k.

Definition 4 indicates that two conditions must be satisfied before a back-end processor can signify that a record is available:

1. The record must not be claimed by another task.

2. If the first condition is, then it must be certified that granting control of the record to T_k would not cause any set of tasks to enter a deadlock-prone state.

Definition 5

The LOCK r_j, T_k command, when issued by B_k to B_j, causes r_j to be marked as locked by T_k in all shared record lists of B_j.

Definition 6

The UNLOCK r_j command causes r_j to be unmarked in all shared record lists.

The purpose of the REQUEST command and the POSITIVE response is to confirm the availability of a record with higher priority tasks. Since the distributed data base environment permits concurrent asynchronous operations on shared data, a back-end processor must query those back-ends that contain higher priority tasks which interact with the requesting task to verify the status of the record. If the record is available, a POSITIVE response is sent. If the record is unavailable, at the time of the REQUEST a LOCK command would

already be in transit to the back-end of the requesting task. The receipt of a LOCK command from a higher priority task invalidates a REQUEST. The LOCK command binds a record to a task while UNLOCK is used to release records.

The functions and responses are employed by the following algorithm to prevent the distributed DBMS from entering a deadlock state.

Algorithm 1

PART A

When task T_k desires to update shared record r_j, the following steps must be taken by B_k to prevent a deadlock state.

1. Check if r_j is marked in any $S_{T,k}$ containing r_j. If so, T_k must wait until B_k receives an UNLOCK r_j command. Note that if r_j is marked in one $S_{T,k}$, it is marked in all $S_{T,k}$.

2. If $\exists$ $S_{T,k}$, such that $m(S_{T,k}) = |X_T| - 1$, then T_k must wait until a record in $S_{T,k}$ is unlocked.

3. Mark r_j with the identifier of T_k in all $S_{T,k}$ containing r_j.

4. For all higher priority tasks in any S_T containing T_k, issue a REQUEST r_j, T_k command to their back-end processors.

5. Wait for POSITIVE r_j responses from all back-ends of step 4.

6. If while waiting, B_k receives a LOCK r_j, T_i command, then B_k must issue UNLOCK r_j commands to all back-ends which have transmitted POSITIVE r_j responses, and then B_k must return to step 1.

7. If while waiting B_k receives a LOCK r_n, T_i command ($r_n \neq r_j$), and $m(S_{T,k}) = |X_T| - 1$, then B_k must issue UNLOCK r_j commands to all back-ends which have transmitted POSITIVE r_j responses and then return to step 2.

8. When B_k receives POSITIVE r_j responses from all tasks in step 4 it issues a LOCK r_j, T_k command to all lower priority tasks in any X_T containing T_k.

9. T_k may then operate upon r_j.

10. Upon completion of the operations in step 9, B_k issues an UNLOCK r_j command to all tasks in any X_T containing T_K.

PART B

When a back-end processor, B_i, receives a REQUEST r_j, T_k command, it transmits a POSITIVE r_j response if the requirements of Def. 4 are satisfied. If a POSITIVE response is transmitted, r_j is marked with the identifier of T_k in all $S_{T,i}$.

PART C

When a back-end processor, B_i, receives a LOCK r_n, T_k command and it does not have a REQUEST r_j command outstanding such that the conditions in steps 6 or 7 of Part A arise, r_n is marked with the identifier of T_k in all $S_{T,i}$.

It must now be demonstrated that Algorithm 1 prevents deadlock.

Lemma 3

Algorithm 1 prevents the system from entering a deadlock-prone state.

Proof

From Def. 1, it can be seen that under all circumstances, for any S_T, $m(S_{T,k}) \leq L(S_T)$ for all back-ends B_k.

Under Algorithm 1, a back-end processor may only issue a LOCK command if $m(S_{T,k}) \leq |X_T|-1$ for all X_T. Thus immediately prior to the issuance of a LOCK command, $L(S_T) \leq |X_T|-1$. After the LOCK command has been issued, the maximum value of $L(S_T)$ is $|X_T|-1$ for all S_T. Therefore according to Lemma 2, if the system operates under Algorithm 1, it cannot enter a deadlock-prone state.

Theorem 1

Algorithm 1 prevents the system from entering a deadlock state.

Proof

The theorem follows immediately from Lemmas 1 and 3.

The following example, illustrates the operating of a distributed DBMS with the deadlock prevention algorithm in effect.

Example 4

Assume the set of tasks in Example 1. We will follow the actions of the back-end processors B_1, B_2, B_3 which control data base access for T_1, T_2, and T_3 respectively. The only task set in which the value of m (S_T) can be greater than 2 is $X_4 = \{T_1, T_2, T_3\}$.

In the example under consideration, $S_4 = \{r_1, r_3, r_7\}$. For notational convenience each $S_{4,i}$ will be denoted by an ordered triple in which the first element corresponds to the task, if any, marking r_1, the second element indicates the task marking r_3, while the final element represents the task marking r_7.

Assume the following set of references in the sample system.

Time	Task	Record Referenced
t_0	T_1	r_1
t_0	T_2	r_7
t_0	T_3	r_3
t_{10}	T_1	r_3
t_{10}	T_2	r_1
t_{10}	T_3	r_7

Once a task receives the second record it has requested, it requires 5 time units to complete its operation on those records.

For purposes of this example, the delays between back-end processors shown below are assumed.

$B_1 \leftrightarrow B_2$ - 2 time units

$B_1 \leftrightarrow B_3$ - 3 time units

$B_2 \leftrightarrow B_3$ - 1 time unit.

Also, let the task priorities be

$T_1 > T_2 > T_3$.

Given the requests listed above the following operations are performed in the system.

1. At time t_0

$S_{4,1} = \{1, \ , \ \}$ $S_{4,2} = \{ \ , \ ,2\}$ $S_{4,3} = \{ \ ,3, \ \}$.

B_1 issues LOCK r_1, T_1 to B_2 and B_3.

T_1 proceeds to operate on r_1.

B_2 issues REQUEST r_7, T_2 to B_1.

B_3 issues REQUEST r_3, T_3 to B_1 and B_2.

2. At time t_1,

B_2 receives REQUEST r_3, T_3.

$S_{4,2} = \{ \ ,3,2 \ \}$.

B_2 transmits a POSITIVE r_3 to T_3.

3. At time t_2,

B_1 receives REQUEST r_7, T_2.

$S_{4,1} = \{1, \ , \ 2 \ \}$.

B_1 Transmits a POSITIVE r_7 to B_2.

B_2 receives a LOCK r_1, T_1.

$S_{4,2} = \{1,3,2\}$.

4. At time t_3,

B_1 receives REQUEST r_3, T_3. Since m $(S_{4,1})$ = 2 the request is ignored.

B_3 receives LOCK r_1, T_1. This command also indicates that the request for r_3 by B_3 will not be granted by T_1. Thus,

$S_{4,3} = \{1, , \}$.

B_3 issues an UNLOCK r_3, T_3 to B_2.

5. At time t_4,

B_2 receives POSITIVE r_7 from B_1.

T_2 proceeds to operate on r_7.

B_2 issues a LOCK r_7, T_2 to B_3.

B_2 also receives UNLOCK r_3, T_3 from B_3.

$$S_{4,2} = \{1, \ ,2\}.$$

6. At time t_5,

B_3 receives LOCK r_7, T_2.

$S_{4,3} = \{1, \ ,2\}$.

7. At time t_{10},

B_1 issues LOCK r_3, T_1 to B_2 and B_3.

$S_{4,1} = \{1,1,2\}$.

T_1 proceeds to operate on r_3.

8. At time t_{12},

B_2 receives LOCK r_1, T_1.

$S_{4,2} = \{1,1,2\}$.

9. At time t_{13},

B_3 receives LOCK r_1, T_1

$S_{4,3} = \{1,1,2\}$.

10. At time t_{15},

B_1 issues UNLOCK r_1 and UNLOCK r_3 to B_2 and B_3.

$S_{4,1} = \{\ ,\ ,\ 2\}$.

11. At time T_{17},

B_2 receives UNLOCK r_1 and UNLOCK r_3 and issues REQUEST r_1, T_2 to B_1

$S_{4,2} = \{2,\ ,2\}$.

12. At time t_{18},

B_3 receives UNLOCK r_1 and UNLOCK r_3 and issues REQUEST r_3, T_3 to B_1 and B_2.

$S_{4,3} = \{\ ,\ 3,\ 2\}$.

13. At time t_{19},

B_1 receives REQUEST r_1, T_2.

$S_{4,1} = \{2,\ ,2\}$.

B_1 issues POSITIVE r_1 to B_2.

B_2 receives REQUEST r_3, T_3.

$S_{4,2} = \{2,3,2\}$.

B_2 issues POSITIVE r_3 to B_3.

14. At time t_{20},

B_3 receives POSITIVE r_3 from B_2.

15. At time t_{21},

B_1 receives REQUEST r_3, T_3.

$S_{4,1} = \{2,3,2\}$.

B_1 issues POSITIVE r_3 to B_3.

B_2 receives POSITIVE r_1 from B_1 and then issues a LOCK r_1, T_2 to B_3 and proceeds to operate upon r_1.

16. At time t_{22}.

B_3 receives LOCK r_1, T_2.

$S_{4,3} = \{2,3,2\}$.

17. At time t_{24},

B_3 receives POSITIVE r_3 from B_1 and then proceeds to operate on r_3.

18. At time t_{26},

B_2 issues UNLOCK r_1 and UNLOCK r_7 to B_1 and B_3.

$S_{4,2} = \{\ ,3,\ \}$.

19. At time t_{27},

B_3 receives UNLOCK r_1 and UNLOCK r_7 from B_2 and then transmits REQUEST r_7, T_3 to B_1 and B_2.

$S_{4,3} = \{\ ,3,3\}$.

20. At time t_{28},

B_1 receives UNLOCK r_1 and UNLOCK r_7 from B_2.

$S_{4,1} = \{\ ,3,\ \}$,

B_2 receives REQUEST r_7, T_3.

B_2 issues a POSITIVE r_7 to B_3.

$S_{4,2} = \{,3,3\}$,

21. At time t_{29},

B_3 receives POSITIVE r_7 from B_2.

22. At time t_{30},

B_1 receives REQUEST r_7, T_3 from B_3.

$S_{4,1} = \{ 3, 3 \}$.

B_1 transmits POSITIVE r_7 to B_3.

23. At time t_{33},

B_3 receives POSITIVE r_7 from B_1 and then begins to operate upon r_7.

7. Efficiency of Deadlock Prevention Algorithm

It is difficult to treat the efficiency of Algorithm 1 without experimental evidence from a prototype distributed DBMS. There are several critical performance factors which could vary among distributed DBMS implementations. Network topology, degree of potential sharing among application tasks, and subschema size are among the system parameters that will have the strongest performance effects.

The number of back-end processors in the network along with the physical distance and type of connections among the back-end processors will influence the amount of communication overhead resulting from deadlock prevention. It should be noted that only back-end processors that execute data base operations for tasks that share data have a need to exchange information in order to prevent deadlock. If both deadlock prevention and a high degree of efficiency are goals of a system design, than data shared by a group of tasks should be controlled by a minimal number of back-end processors. (Ideally, each such unit of shared data would reside on the storage of a single back-end processor.)

One environment under which the deadlock prevention algorithm could degrade performance is an on-line system in which each user may access any record in the entire data base. In this situation, the deadlock prevention algorithm would force the DBMS to operate in a single threaded mode. If the sub-schema concept is applied to this unrestricted on-line environment, the undesireable effects of deadlock prevention can be virtually eliminated. Instead of permitting each on-line command unrestricted access to the entire data base, the data base can be partitioned into a logical collection of sub schemas. Whenever a user issues an on-line data base request, the appropriate sub-schema is invoked prior to the actual execution of the command.

The sub-schemas should be defined to encompass only that portion of the data base that the command may access. For example, if an airline reservation clerk updates a passenger list, the sub-schema would contain the passenger list for a given flight.

In an on-line environment in which the data base has been partitioned into sub-schemas the user need not sacrifice any flexibility of data access. Each user would interface with a re-entrant control program which parses each request, invokes the applicable sub-schema and then activates a host task to execute the request. By organizing an on-line system in this manner the negative performance effects of deadlock prevention are minimized.

8. Conclusion

The approach to deadlock prevention described here is a dynamic pre-claim technique [8] since it implicitly locks a set of records that could be required for an operation. The deadlock prevention scheme proposed for distributed data base systems has some similarity to the data base deadlock prevention mechanisms of Lomet [16] and Chu and Ohlmacher [4]. Lomet employs a graph-theoretical technique to avoiding deadlock. However, the information contained in the graphs is essentially the same as that maintained in the shared record list. The version of Lomet's algorithm presented in reference [16] does not consider the performance effects of operation in a distributed environment.

The process set of Chu and Ohlmacher is very close conceptually to the shared record list. The algorithm of Chu and Ohlmacher is also intended for distributed systems. The technique developed here differs from the approach of Chu and Ohlmacher in that it operates at the record level and in that a requesting task is given control of only that part of its shared record list necessary to avoid a deadlock-prone state. The feasibility of

database sharing at the record level has been studied using simulation by Shemer and Collmeyer [20], who projected that even with a high degree of contention, performance degradation due to overhead would be minimal. Presently, several commercially available, single-machine data base systems provide data sharing and locking at the record level [22].

The deadlock prevention algorithm is intended to prevent all possible deadlocks while allowing maximum data base sharing at the record level. The results of the Section 6 demonstrate that the algorithm meets these criteria. Naturally, deadlock prevention incurs some overhead. However, careful planning by the designer of a distributed data base application who is cognizant of the operation of the prevention algorithm can result in minimization of the overhead. For a distributed DBMS application to operate efficiently under the deadlock prevention algorithm, it is important that the data base be partitioned into sub-schemas. However, once the sub-schema is defined, the individual application programs need not be aware of the mechanics of the deadlock prevention algorithm.

Due to the infrequency of deadlock situations, a deadlock detection schema requires less overhead than deadlock prevention in a single machine DBMS. However, the uncertain amount of overhead in distributed DBMS rollback added to the fixed overhead of the timeout mechanism, both of which are necessary operations in deadlock detection, leads to proposing deadlock prevention as the more satisfactory mechanism for handling deadlocks in a distributed data base. The subject of rollback for a distributed DBMS is treated in reference [17], which presents an algorithm for minimizing the overhead of the rollback operation.

The lists computed by the prevention algorithm have potential application in two critical design areas of distributed data base. The size of a task

interaction list, X_T, is an indicator of the amount of interference resulting from the activation of a data base task. Since task interference has an effect in system performance, the scheduler could use the size of X_T as one of the weighting factors in the scheduling algorithm.

The contents of the shared record list would be of use to a prepaging memory manager [23]. Records that are unlocked, yet only requestable by a single task, could be transmitted to the page buffer associated with that task. The shared record list would be particularly valuable when used in conjunction with a Markovian paging model [1,11].

9. References

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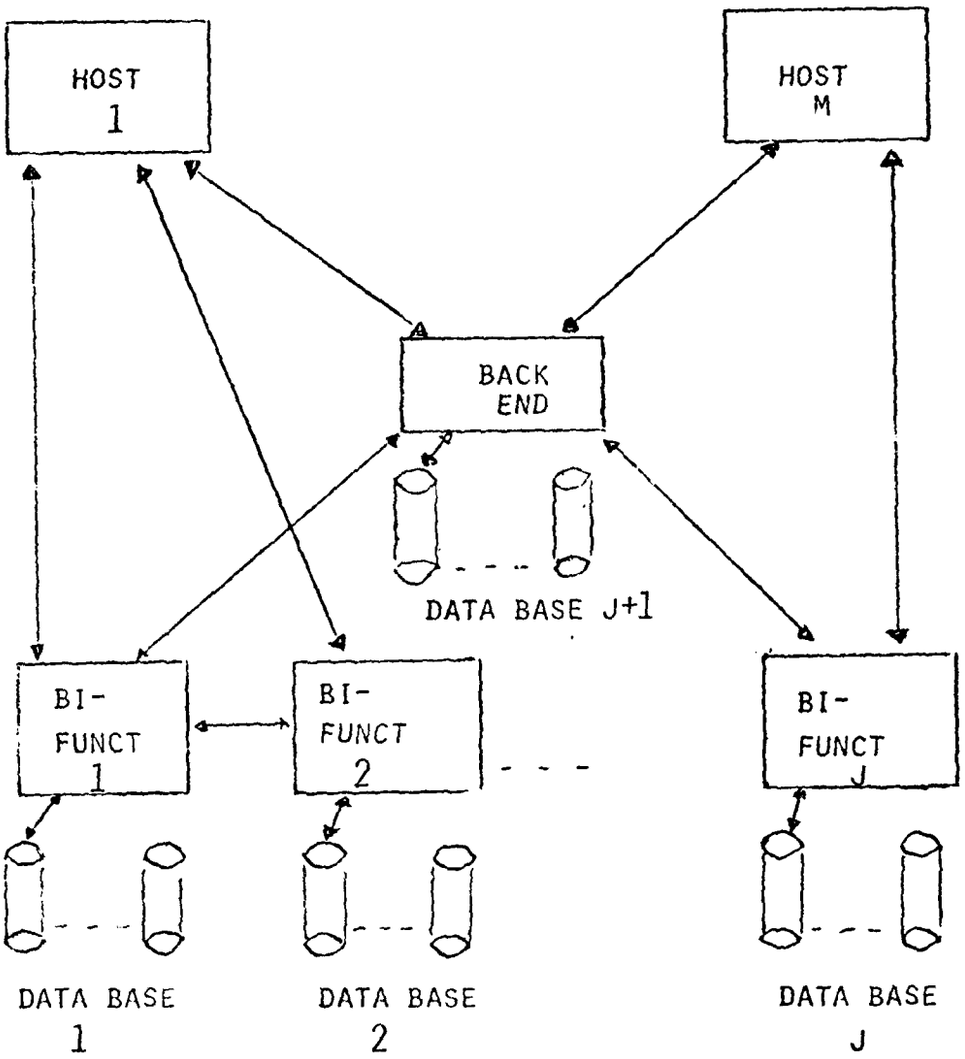
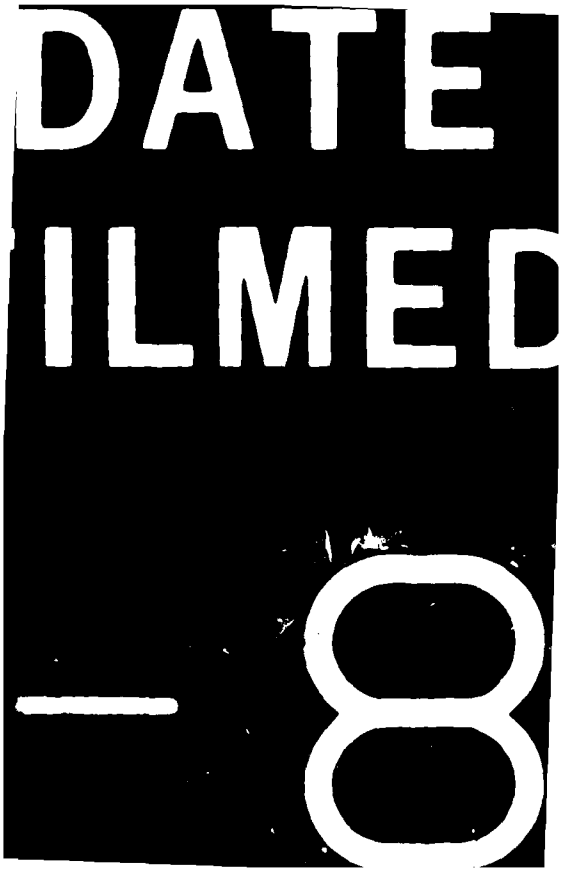


FIGURE 1

DISTRIBUTED DBMS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